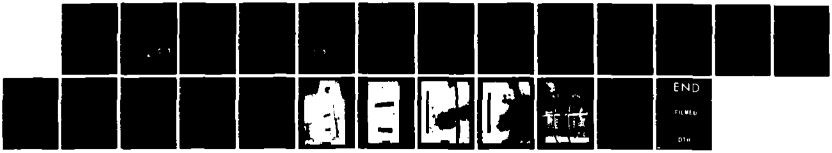
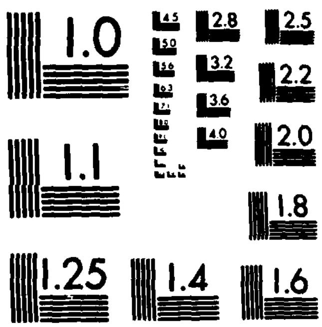
AD-A149 055 FLASHOVER FAILURES FROM WET-WIRE ARCING AND TRACKING (U) NAVAL RESEARCH LAB WASHINGTON DC F J CAMPBELL 17 DEC 84 NRL-MR-5508 1/1

UNCLASSIFIED F/G 9/3 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

2

NRL Memorandum Report 5508

AD-A149 055

Flashover Failures from Wet-Wire Arcing and Tracking

F. J. CAMPBELL

Radiation-Matter Interactions Branch
Condensed Matter and Radiation Sciences Division

December 17, 1984

NAVAL RESEARCH LABORATORY
Washington, D.C.

Approved for public release; distribution unlimited.

SECUR CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b. RESTRICTIVE MARKINGS:

2a. SECURITY CLASSIFICATION AUTHORITY:

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE:

3. DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S): NRL Memorandum Report 5508

5. MONITORING ORGANIZATION REPORT NUMBER(S):

6a. NAME OF PERFORMING ORGANIZATION: Naval Research Laboratory

6b. OFFICE SYMBOL (If applicable): Code 6654

7a. NAME OF MONITORING ORGANIZATION:

6c. ADDRESS (City, State, and ZIP Code): Washington, DC 20375-5000

7b. ADDRESS (City, State, and ZIP Code):

8a. NAME OF FUNDING / SPONSORING ORGANIZATION: Naval Air Systems Command

8b. OFFICE SYMBOL (If applicable):

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: N0001985WR5124W

8c. ADDRESS (City, State, and ZIP Code): Washington, DC 20361

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
62520			DN291-124

11. TITLE (Include Security Classification): Flashover Failures from Wet-Wire Arcing and Tracking

12. PERSONAL AUTHOR(S): Campbell, F.J.

13a. TYPE OF REPORT: Annual

13b. TIME COVERED: FROM 10/83 TO 9/84

14. DATE OF REPORT (Year, Month, Day): 1984 December 17

15. PAGE COUNT: 24

16. SUPPLEMENTARY NOTATION:

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number): Wire bundles; Aircraft; Fires; Flashover failures; Arcing and tracking; Electrical insulation

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Flashover failure occurs in a wire bundle as a high-energy current surge between a bare conductor delivering power and a ground-plane (e.g. metal framework or wire shielding) as the conductive path across adjacent wires approaches zero resistance. It happens as a violent blazing flashover in which the copper of the bare wire melts and splatters — causing melting and burn-through of some of the adjacent wires in the bundle. Thus, it could produce the loss of a number of circuits at once. Under service stress conditions the process leading to a flashover could begin as the wire insulation initially deteriorates by cracking or chaffing and the surfaces of adjacent wires in the bundle become contaminated due to salt spray, mist, fog and high humidity. Under these conditions, typical of Naval aircraft service, arcing and tracking initiate and eventually localized spots extend into a continuous carbonaceous path, bridging the wires from the fault to ground. At some point the wetting is no longer necessary to sustain the current, and the flashover strikes.

(Continues)

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL: F. J. Campbell

22b. TELEPHONE (Include Area Code): (202) 767-2414

22c. OFFICE SYMBOL: Code 6650

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

19. ABSTRACT (Continued)

This phenomena is known to develop on the surfaces of polymeric materials that readily carbonize when pyrolized and the susceptibility to fail by this mechanism is characterized in standard arcing and tracking tests. The phenyl-containing polymeric materials fall into this class. Laboratory tests have demonstrated that flashover will occur on wires insulated with a hi-phenyl polyimide composite and also on wires insulated with a polyphenyl ketone polymer; whereas, two types of a polytetrafluoroethylene insulation did not carbonize or flashover in the test. These results are in agreement with other references on arcing and tracking studies.

A

CONTENTS

FLASHOVER FAILURES FROM WET-WIRE ARCING AND TRACKING

BACKGROUND

Electrical wires in Naval aircraft are exposed to the severe environment of aircraft carriers and tropical island bases. The environment provides a source of surface contamination of salt spray and fog. The combination of the buildup of salt and exposure to moisture due to mist, fog, or condensation during high humidity conditions could lead to the development of large leakage currents and surface discharges across the surfaces of some types of wire insulation. These will first appear as scintillating arcs across the surface of the insulation of these wires in a tightly bound bundle wherever there is an exposed conductor in a load-carrying wire in the bundle, and in the same vicinity the bundle is touching a metal ground plane. It might also occur between bare conductors of opposite polarity within a bundle. The tracking and surface flashover of these discharges can cause carbonization or other deterioration of the organic insulation materials in the view of the fact that the continuous arcing emissions will produce localized surface temperatures on the order of 1000°C(1). At these high temperatures carbonization will occur below the arc paths on the surfaces of highly phenylated polymeric materials such as aromatic epoxies, phenolics, and especially those with the para-phenylene group in the polymer chain. Thus, these materials contain molecular structures similar to

Manuscript approved November 30, 1984.

graphite and have a high carbon-to-hydrogen ratio. Kapton* is a polyimide film which has this characteristic structure. Under standardized tests for tracking and erosion by the dust and fog method (2), the inclined-plane method (3), and the drop method (4), materials of this type have relatively short life (5,6).

Initially, carbonization occurs at rather small localized spots where arcs temporarily dwell at these dry bands, and the carbon track phenomena may appear in short, isolated spots. Eventually these initial spots or short stretches of carbonization will extend stepwise by arcing from these ends to adjacent saltwater films and grow into a continuous network across surfaces until bridging between exposed conductors occurs, and a highly conductive carbon path is formed that does not depend upon the wetting to sustain the current flow. From then on the Joule heating or a violent flashover could produce the type of fires or damaged wire bundles which have been reported in recent years in aircraft wired with Kapton insulated wires. Flashover failure can also occur with other insulation materials of the polyaromatic type that carbonize by the wet-arcing and tracking mechanism. The Experimental Procedure section of this report describes the progressive action and flashover breakdown observed on Kapton wire bundles, and the results of experiments on PEEK* (polyetheretherketone) and ETFE (copolymer of ethylene and tetrafluoroethylene) insulated wires are described in the section titled "Other Wires Studied". The results were in agreement with the material differences discussed in the next paragraph.

*Registered trademark of E. I. du Pont de Nemours & Co., Inc.

*Registered trademark of Imperial Chemical Industries

The voltage level of aircraft electrical systems is sufficient to cause carbon tracking on susceptible materials, but in recent years essentially non-carbonizing resin formulations have been developed from aliphatic resins and fillers which do not "track" under outdoor conditions (7). The degree of resistance to tracking of a material depends on its chemical nature and the manner in which it breaks down when subjected to the very high temperatures of the small surface arcs. Thus, the degradation of a polyaromatic material produces much free carbon which can form conducting tracks. On the other hand the degradation products of ethylenic-type polymers (polyethylene, polytetrafluorethylene) are gaseous, and the materials do not track (8).

The problems of flashover failure are magnified for MIL-W-81381 wires because the Kapton insulation on these wires develops radial cracks when it undergoes hydrolytic degradation, which occurs at a relatively high rate in high moisture environments. This deterioration process will occur in several types of polyimide insulation of aircraft hook-up wire , and it has been observed in service frequently enough to become a major subject of concern for the safety and maintenance engineers of Naval aircraft centers (9). It also has been demonstrated in laboratory experiments on MIL-W-81381 wires insulated with Kapton, a polyimide material.(10). The deterioration mechanism has been found to be a chain scission reaction that materializes as embrittlement and fraying of the polyimide in both the top-coating and the tape wrapping of the wire insulation. When the wires are under stress, such as occurs at the sharp bends near connections which are common in airframe wiring practices, the radial cracks propagate completely through the insulation material to the conductor. The bare conductor is then exposed to the previously described moist, salty environment, and when the

circuit is energized, wet surface arcing develops across the electrolyte film connecting the interfaces of adjacent wires in the bundle, completing the circuit to ground or another bare wire. The Joule heating produced by this arcing current begins to deteriorate the insulation surface and also produces localized dry bands at which arcing is more readily repeated when the surface wetting reoccurs. Thus, each time the aircraft descends from the extreme cold of a high-altitude mission into the high humidity on the carrier deck, the condensation on contaminated wires repeats the cycle and surface aging continues until failure strikes.

EXPERIMENTAL PROCEDURE

A seven-wire bundle was used in this laboratory simulation experiment because of its simple symmetry (six of the wires encircle the inner one). The insulation on one of the outer wires was radially cut to simulate the cracking produced by hydrolytic degradation. The bundle was secured on both sides of the crack with heat-shrinkable tubing. The damaged wire was positioned on the outer ring so that it was on top when the bundle was draped over a 1.25 cm diameter aluminum rod. This rod was laying on an aluminum plate. Each wire in the bundle had about 1 cm of insulation stripped from one end so they could each be clipped to wires leading from the circuit breaker box in which each was in series with a Klixon* 5-amp circuit breaker (Series 7274-11) leading from the bus bar on the positive side of the power line. Thus, each wire in the bundle was at a 120 volt potential with respect to the aluminum rod clipped to the ground side of the circuit. This assembly was then positioned under a pipet from which a one-percent solution of sodium chloride in water was dropped directly onto the cracked segment of the damaged wire at a constant rate of approximately ten drops per minute. The drop rate was controlled by a very slow-acting peristaltic pump equipped with a flow rate controller. A photograph of this system, taken after the flashover failure occurred, is shown in Figure 1.

*Registered trademark of Texas Instruments, Inc.

The experiment was applied to over sixty bundles of Kapton wire, representing three different manufacturers. Some variations in the drop rate and the bundle configuration were also applied. The results of the experiments demonstrated that the time to achieve the flashover failure would occur within a time span of several minutes to about one hour, depending on the tightness of the bundle and other variations of the assembly. They also demonstrated that the flashover failure due to the arcing and tracking initiated by one damaged wire will also destroy some or all of the other wires in the bundle, as is evident in the close up photo of the bundle shown in Figure 2, as it appeared after the flashover. The circuit breaker of each of these broken wires tripped at the flashover, so it can be seen which ones were severed by the intense heat of the flash. Thus, if this phenomena occurs in service, then control of more than one essential electrical component could be lost.

The ammeter shown in Figure 1 provided an indication of the approaching failure as the experiment progressed. During the initial tracking and arcing of the cracked wire, the current surges generally remained below 0.5 amps. As the tracking and arcing became more continuous and severe, a more constant current ranging between 0.5 and 1.5 amps was detected. At this point the spikes in the current exceeded 5 amps and caused the circuit breakers to blow. This occured with an instantaneous, blazing flashover in which the conductor of the damaged wire melted and splattered, causing the melting and burning of some of the adjacent wires in the bundle at the same instant.

In order to illustrate this sequence more completely a videotape was prepared that shows each of the above steps, from the preparation of the bundle to the after effects of the flashover. Two of the frames were photographed from this film in order to capture the fast moving action. Figure 3 shows the arcing which occurs as it becomes more severe (6 min, 1 sec from the start), and Figure 4 shows the intense flash, with streaks of molten copper and aluminum coming out of the burning area (6 min, 41 sec.). A photo of the remains is shown in Figure 2, where the wire surfaces are covered with char, and the tips of the conductors and the aluminum rod show evidence of melting and cratering from the blast of the flashover.

ADDITIONAL WIRE STUDIES

The same experimental procedure was applied to three other types of insulated wire that have been proposed as replacement for the MIL-W-81381 type in future aircraft wiring assemblies. These were as follows: ETFE (ethylene tetrafluoroethylene) commercially available as TEFZEL (MIL-W-22759/16), Crosslinked ETFE (MIL-W-22759/34) and Poly-ether-ether-ketone, PEEK (not a MIL-Spec wire at present). The results of these experiments on the experimental wire bundles are displayed together in Figure 5. Both the Tefzel and the X-linked Tefzel wires reacted about the same to the deteriorating process of the salt water/voltage potential of the experiment. However, flashover did not occur because there was no carbonization buildup resulting from the arcing and tracking. Although arcing did occur, it was much less intense than that described above for Kapton wires, and the current pulses were too small to be observed on the ammeter scale. After several hours it was noticed that the conductor of the intentionally bared wire on top of the bundle had corroded in two due to the acid formation from the electrolytic reaction of the salt water. A grayish-green deposit was collecting on the adjacent wires, but it did not contribute to the arcing and tracking. As discussed in the Introduction the Tefzel is a polymer of the type that decomposes into gaseous products under high temperatures so it was not expected to carbonize to form a conductive, flashover path.

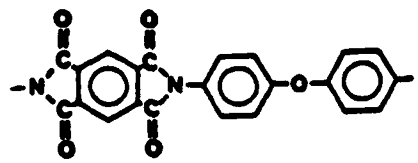
The PEEK insulated wires were tested in bundles by the same procedure. These also exhibited intense arcing and tracking very quickly with flashover

*Registered trademark of E. I. du Pont de Nemours & Co., Inc.

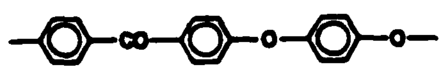
taking place in the range of one to ten minutes. This was expected to occur since the polymer chain is also one that is highly aromatic which forms carbon when pyrolyzed.

DISCUSSION

There have been a number of research studies reported that provide detailed evidence of the production of conductive carbon formations when polymers containing the para-phenylene structure in the polymer chain are pyrolyzed at high temperatures. An extensive study of Kapton pyrolysis products formed at various temperatures showed that at temperatures above 650°C the structural form changed from that of amorphous carbon to mixtures containing increasing amounts of the regular ordered graphitic structure in which the hexagonal rings of bonded carbon form a continuous, highly conductive network (11,12). Carbon fibers commercially prepared from similar starting polymers also show similar graphitic, highly conductive structures. The Kapton polymer chain has a repeating unit in which the para-phenylene group is present, as shown in the following atomic structure:



Poly-ether-ether-ketone (PEEK) is also of the para-phenylene class of polymers, having a repeating unit as follows:



We have been unable to find reported studies of its pyrolysis products or of tracking tests in current literature, but from the similarity of its chain structure and the results of our flashover experiments on PEEK insulated wires it is evident that it, too, forms a highly conductive carbonized product at the pyrolyzing temperatures reached in the arcs observed in these experiments.

National and international testing committees have recognized the need to determine the nature of the tracks formed and the time required to develop them on flat polymeric surfaces under standardized conditions. The results are usually reported as the "relative tracking index" (RTI), which then provides a significant classification order, influencing the selection of materials for applications in electrical equipment operating in severe environments. Ratings of Kapton film (500H) show that it is very good for dry arc resistance, with a RTI of 181-183 (by ASTM-495) (13), where 60 and over is acceptable; whereas, when tested under standard wet conditions it has a CTI (Comparative Tracking Index) of 140 (by IEC-112) (4), where 175 is the acceptable minimum (14).

Since there is no previously published test procedure for determining a relative tracking classification for wire and cable, it must be assumed that these insulating materials would compare to some degree as having ratings similar to those obtained by the flat film test results. The time to flashover failure in our experiments varied from a few minutes to over an hour for bundles of wire from the same spool, depending on many variable factors of the experiment. Therefore, it does not seem possible at this stage of our program to rate the Kapton wires from different manufacturers with respect to the time for flashover to occur as an index of their susceptibility to the flashover failure mechanism. However, it would be a distinctive service to the aircraft electrical systems engineers for a wire test standardization group (such as ASTM D09.16) to undertake the development of a procedure for this purpose.

FUTURE STUDIES

The fractured wire bundles observed in this laboratory test appear very similar to the descriptions given of damaged bundles found in real aircraft. Some mechanics and maintenance inspectors in the Navy and Air Force after seeing the videotape of this experiment have asked for a continuation of the study. The planned continuation will investigate effects of other variables. Some of those suggested are as follows:

Other conductive solutions:

- lower concentrations of NaCl.
- various concentrations of MIL-C-43616 cleaning compounds.
- sea water solutions.

Cycles of above.

Cycles of above with drying and fog or high humidity exposure steps.

Other circuit variations to measure the time for the conductor to erode-in-two if the insulation does not carbonize.

Aged wire insulation instead of newly-prepared seven-wire bundles.

Larger bundles

- mixed wire types in bundles.
- bundles carrying different voltages, e.g.:
    - 28 volts dc.
    - coax cables.
    - twisted pair shielded cables.

Damage the wire by abrasion against a sharp edge

-before the test.

-during the test.

Develop pre-failure detection instrumentation for use as a preventative maintenance method.

In addition to these experimental studies a planned research program will study the chemical mechanisms of the degradation under operational stresses in order to develop a sensitive chemical method for measuring remaining life. It will also develop the methodology for applying multi-factor stress aging in order to predict operating life in the total environment of Naval aviation service conditions such as temperature, humidity, mechanical stresses (bending, flexing, vibrating) and electrical stresses.

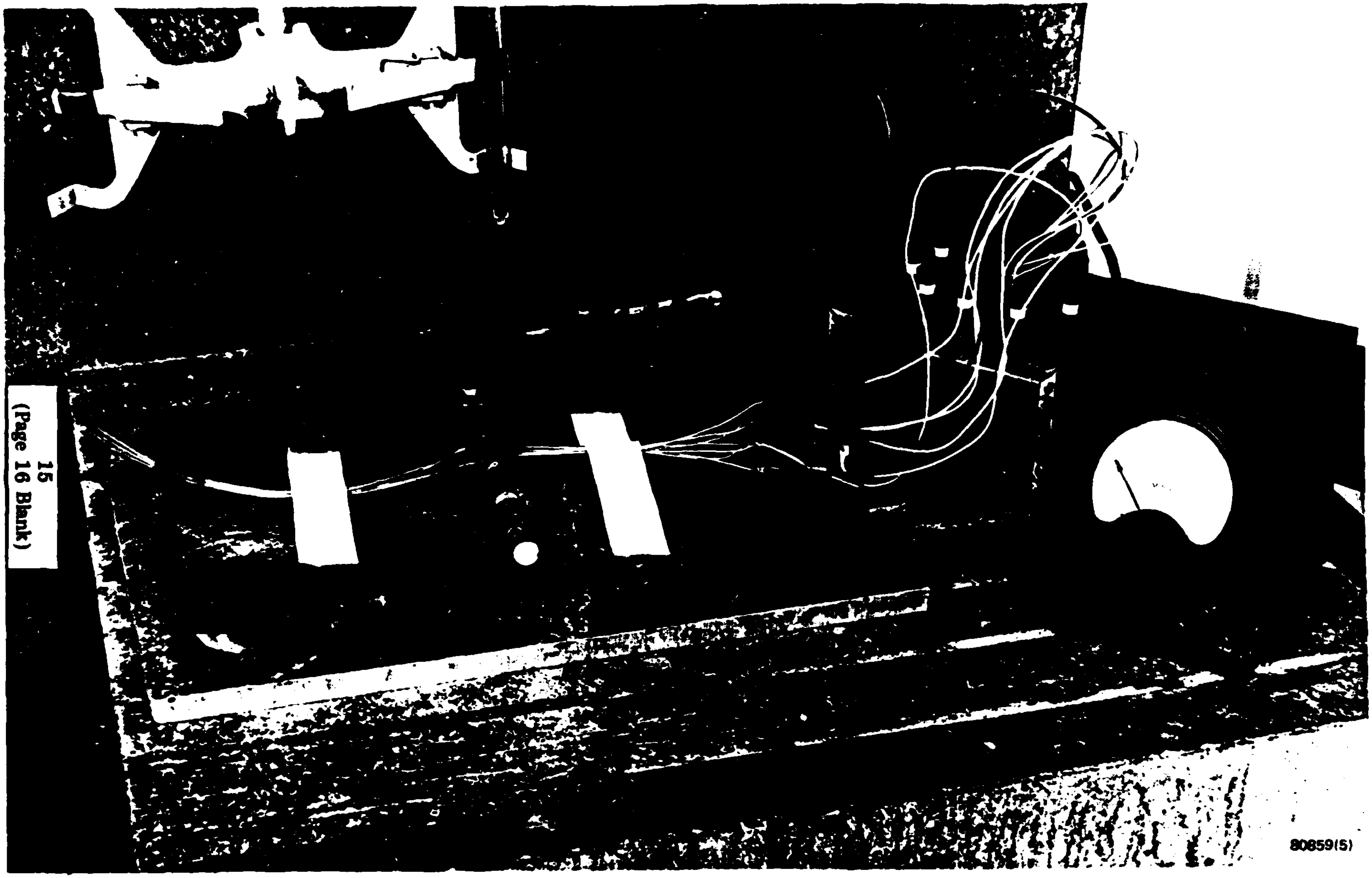


Figure 1: Flashover experiment set-up, showing a bundle of kapton insulated wire after the failure.

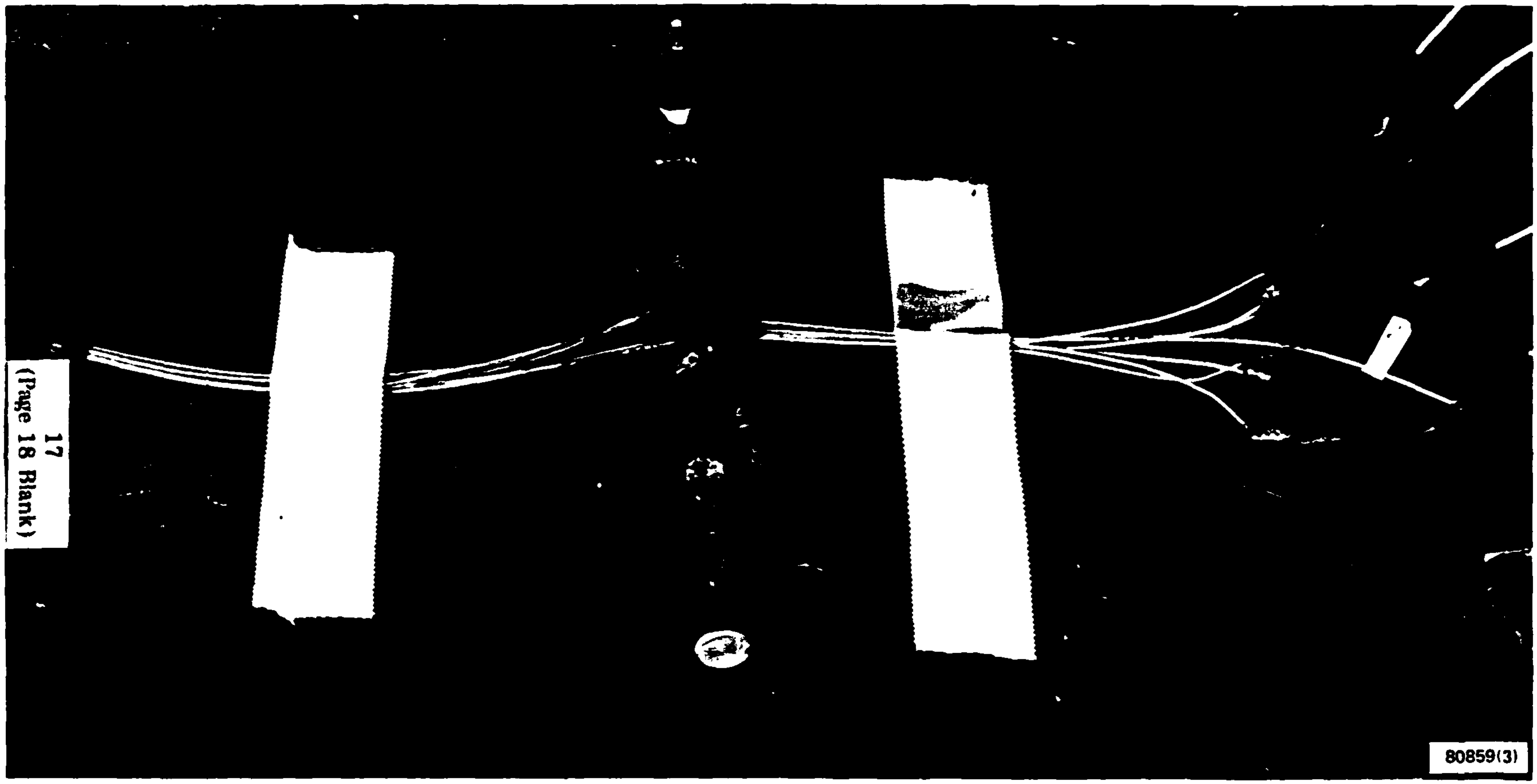


Figure 2: Close-up photo of the failed Kapton bundle after the flashover, showing the melted wires and crater in the grounded aluminum rod resulting from the intense heat of the flashover blast.

Figure 3: One frame from the videotape taken during the initial arcing and tracking that leads to flashover failure.

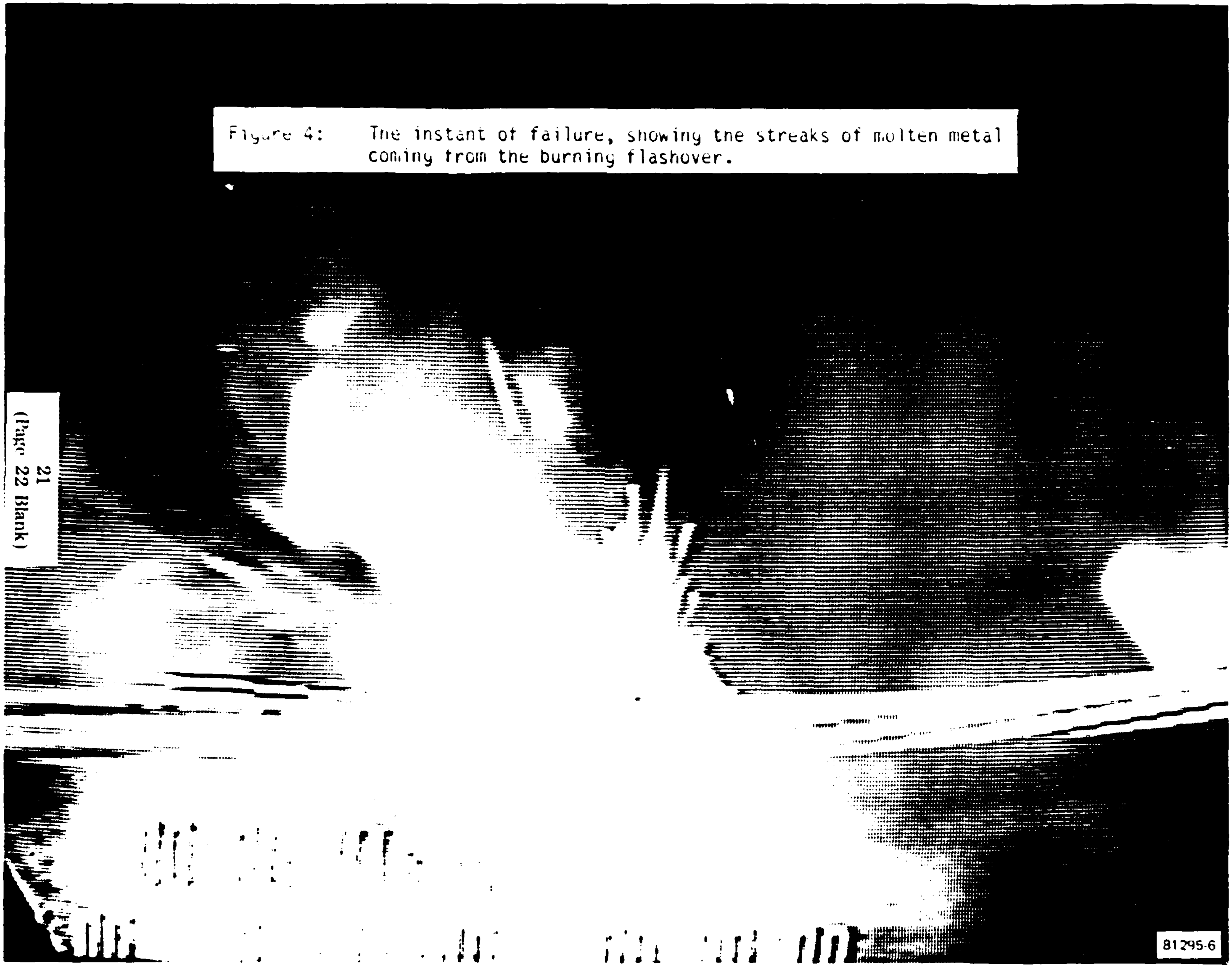


Figure 4: The instant of failure, showing the streaks of molten metal coming from the burning flashover.

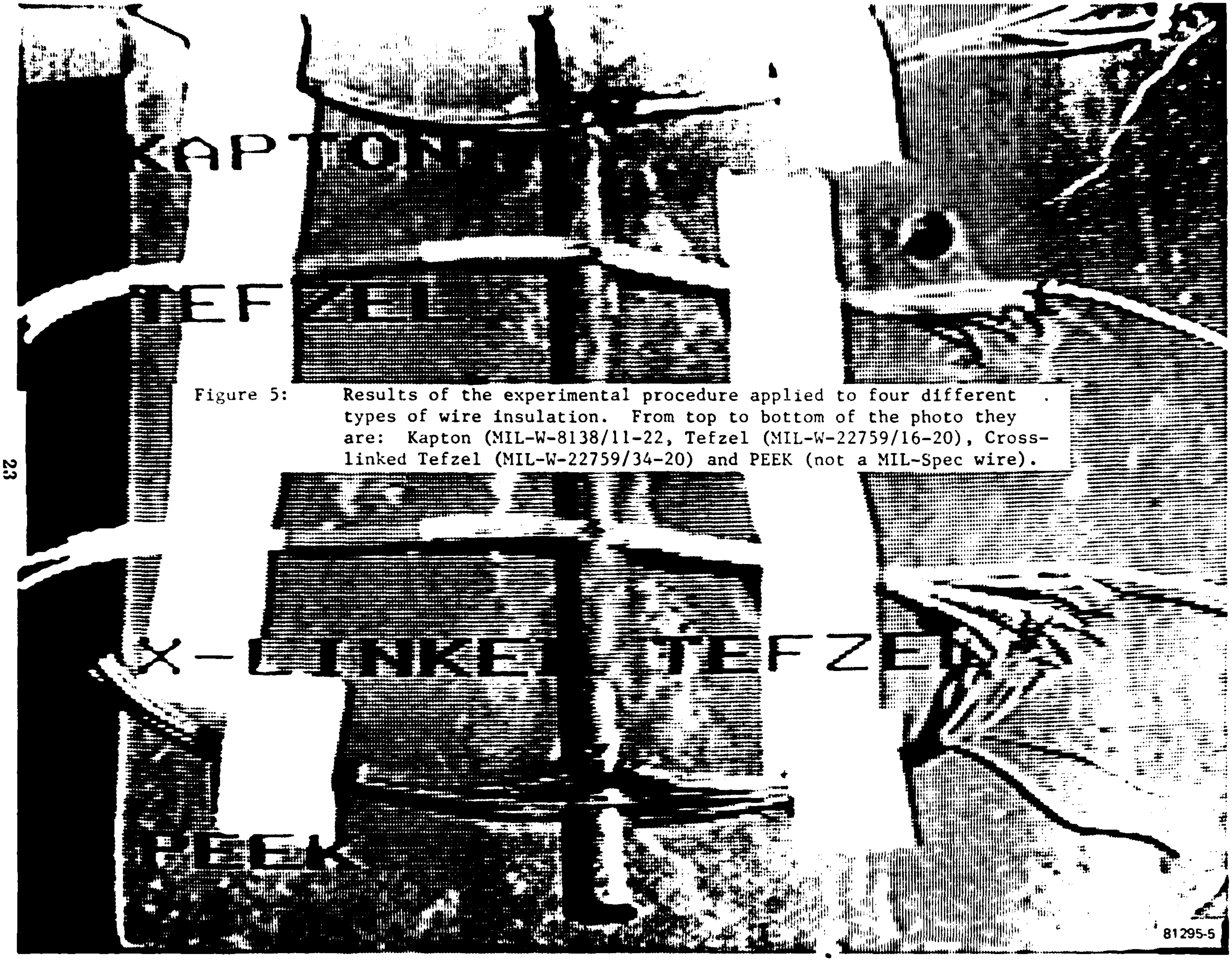


Figure 5: Results of the experimental procedure applied to four different types of wire insulation. From top to bottom of the photo they are: Kapton (MIL-W-8138/11-22, Tefzel (MIL-W-22759/16-20), Cross-linked Tefzel (MIL-W-22759/34-20) and PEEK (not a MIL-Spec wire).

REFERENCES

1. T.W. Dakin, "The Theory of Aging in Electrical Insulating Materials", IEEE Winter Power Meeting, Conference Paper No. 70CP236-PWR (1970).

2. "Standard Test Method for Dust-and-Fog Tracking and Erosion Resistance of Electrical Insulating Materials", ASTM D-2132. ASTM Book of Standards, Vol. 10, American Society for Testing and Materials, Philadelphia, PA., (1984).

3. "Standard Test Method for Liquid-Contaminant, Inclined-Plane Tracking and Erosion of Insulating Materials", ASTM D-2303, ASTM Book of Standards, Vol. 10, American Society for Testing and Materials, Philadelphia, PA., (1984).

4. "Recommended Method for Determining the Comparative Tracking Index of Solid Insulating Materials Under Moist Conditions", IEC Publication 112, International Electrotechnical Commission, Geneva, Switzerland.

5. M. Kurtz, "A Comparison of Tracking Test Methods", Proc. 9th Electrical Insulation Conference, IEEE Publication No. 69C33-EI, p. 46-50 (1969).

6. N. Nishida, N. Yoshimura and F. Noto, "Wetting and Tracking Breakdown of Organic Insulating Materials in an Atmosphere of Mist", 1978 Annual Conference on Electrical Insulation and Dielectric Phenomena, p. 229-238, National Academy of Sciences (1978).

7. D. F. Fink and H. W. Beaty, Standard Handbook for Electrical Engineers, 11th Ed., p. 4-128 (1978).

8. A. G. Day and D. J. Stonard, "Creepage and Clearance Distances in Electrical Equipment for Shipboard Use", IEEE Transactions on Electrical Insulation, Vol. EI-12, No. 3, p. 191-199 (1977).

9. R. V. Hartman, "Unsafe Aircraft Wiring Poses Expensive Problem", Defense Electronics, p. 60-70, January 1983.

10. F. J. Campbell, "Temperature Dependence of Hydrolysis of Polyimide Wire Insulation", NRL Memorandum Report 5158, Naval Research Laboratory, Washington, D.C., August 4, 1983.

11. F. P. Gay and C. E. Berr, "Polypyromellitimides: Details of Pyrolysis", Journal of Polymer Science: Part A-1, Vol. 6, p. 1935-1943 (1968).

12. H. B. Brom, Y. Tomkiewicz, A Aviram, A. Broers and B. Sunners, "On a New Conducting Polymer-Pyrolyzed KAPTON", Solid State Communications, Vol. 35, p. 135-139 (1980).

13. "Standard Test Method for High-Voltage, Low-Current Arc Resistance of Solid Electrical Insulating Materials", ASTM D-495, ASTM Book of Standards, Vol. 10, American Society for Testing and Materials, Philadelphia, PA., (1984).

14. Underwriters Laboratories Inc., <u>Recognized Component Directory</u>, Vol. 1., p. 802 (1984).

END

FILMED

2-85

DTIC